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MODERN METHODS FOR THE ARTIFICIAL DISSIPATION OF FOG AND LOW CLOUDS AND EXPERIENCE IN USING THESE METHODS FOR AVIATION PURPOSES

by

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13. ABSTRACT

This is a review of the status of development of methods for the artificial dissipation of low-level clouds and fogs. A clssification of dissipation methods is given. The classification was made on the basis of the physical processes capable of leading to an improvement of visibility in a fog. The classification makes it possible to analyze any modification methods by comparing them with the most characteristic methods listed in the table. It is proposed that the specific expenditures on energy (reagent) during a definite period be regarded as the principal criterion of method efficiency. The minimum specific expenditures on fog dissipation for different modification methods and durations of clearing the zone of 0.5 and 15 minutes are compared. The minimum expenditures were determined applying the laws of conservation of energy and cannot be reduced by any improvement in technical equipment and the modification.

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Introduction

The present increase in air transportation and its even greater increase in the future stress the need for measures directed at increasing the regularity and safety of air operations.

Air transport operations are greatly disrupted by such unfavorable weather conditions as fog and low cloud cover. According to data presented by Beckwith [1], losses undergone by US airlines from December 1962 through March 1963 due to fog and low cloud cover amounted to about $35 million. I. 1964, regularly scheduled flights of 12.8 million kilometers had to be cancelled for the same reasons.

Cases of sudden closings of airports are particularly dangerous, possibly leading to emergencies and accidents.

The harmful effect of fog and low cloud cover on air transport operations can be reduced, basically in one of two ways:

1) by improving instrument landing equipment;

2) by artificial improvement of visibility by using active control methods.

The opinion exists that the first method is the most universal, and the ever-increasing use of automatic landing equipment reduces, to a certain extent, the urgent need for developing and introducing methods of controlling fog and low cloud cover.

However, as shown by experiments carried out in the US recently by United Air Lines [2], the question of the feasibility of developing one method or the other should be solved specifically for each airport on the basis of climatological data and the situation at the airport. As an example, Collins [2] examines the question of the profitability of the use of landing-system equipment at seven US airports. For these airports he determined the losses suffered by United due to closing of the airports with varying degrees of visibility. The results of these calculations are shown by curve II in Fig. 1. It should be noted that at the examined airports the weather minimums with visibility close to 0-0 in conjunction with climatic conditions are only very rarely observed. As a result, the loss due to airport closings with such gradations of visibility is slight. Curve I shows the cost of the instrument-landing equipment under various conditions. Curve III gives an idea of the total expenditures when using landing equipment. As can be seen from the figure, the equipment cost increases rapidly with reductions in visibility. As a result, with visibility below 200-1/2 (cloud ceiling 200 m, visibility 800 m) expenditures on equipment can be justified only after several years.

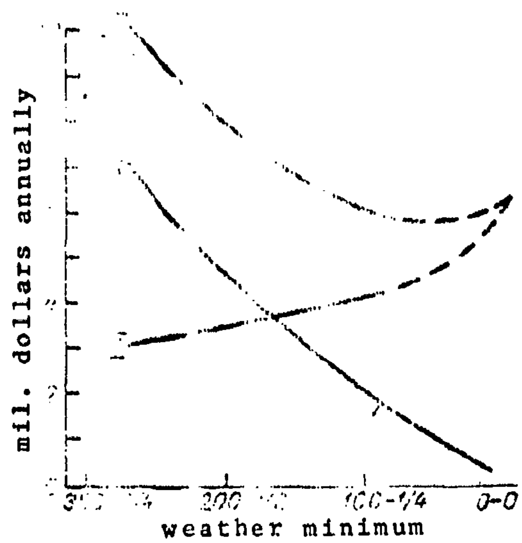

Fig. 1. Expenses incurred in using instrument-landing equipment at US airports, and losses attributed to airport closings.

With visibility of about 30-1/4, more than 10 years are needed to justify this.

Detailed studies must be made for each airport. At the same time we should examine the economic aspects of artificial dissipation of fog and clouds. Since the cost of operations to dissipate supercooled and warm clouds and fog differs, for each airport we should determine the relationship between these types of weather conditions. A comparison of expenditures for equipping airports with instrument-landing equipment and the cost of dissipation operations with the sum of the avoided losses should be the criterion for the use, at each specific airport, of one or the other methods for reducing the harmful effect of clouds and fog.

The present state of methods for artificial dissipation of fog and clouds

To satisfy the requirements of aviation we must have a sufficiently reliable method for controlling clouds and fog, capable of assuring a certain duration for the zone of improved visibility to plan aircraft landing approaches and preparations for takeoff. Solution to this problem requires knowledge of the physical and meteorological conditions leading to clearing conditions.

As a result of theoretical and experimental studies carried out up to the present time, all possible methods for artificially improving the visibility can be categorized on the basis of the physical processes which determine fog dissipation. There exist only three methods for improving visibility in fog: 1) evaporation of the drops, 2) removal of the drops from the cleared volume, and 3) coagulation of the fog drops. Based on this, all seeding methods can be divided into three groups. Table 1 gives a classification of seeding methods, constructed on the basis of this principle [6].

This allows us to analyze any seeding methods by comparing them with the most characteristic methods given in the table. Such

Table 1. Classification of seeding methods

Process of fog dissipation	Seeding process	Equipment and types of seeding, reagents
Evaporation of drops	Heating the fog (thermal methods)	Ideal fuel Hydrocarbon fuel Exothermal reactions Stimulation of the absorption of solar radiation Adiabatic compression
	Absorption of water vapor	Cooling agents Ice-forming aerosols Soluble substances Chemisorption agents Fine-pore sorbents
Removal of drops	Removal of drops	Electric field
	Removal of drops together with air	Aeration of the cleared zone Forced filtration of the fog
Coagulation	Drop coagulation on reagent particles	Sprayed water Charged particles Particles with large specific surface
	Stimulation of mutual coagulation of fog drops	Electric field Acoustic field
	Coagulation in collectors	Natural filtration on grids

a systemization allows the proposal and use of quantitative criteria to compare the various methods. As one of the criteria of effectiveness we can use the energy or reagent expenditure for fog dissipation in a unit volume of air. We should also take into account the meteorological features of the fog and use the second effectiveness factor of the method – the time expended on formation of the cleared zone. This criterion determines the total expenditures of energy (reagent) on clearing a specific object.

Table 2 compares the values of minimum specific energy (reagent) used to dissipate fog using various seeding methods. The first line pertains only to supercooled fog. The figures in the remaining lines were obtained at +5°C with fog-seeding methods which are

Table 2. Minimum energy used to dissipate fog

Seeding process	Minimum energy, cal/m^3 (reagent used, g/m^3)		Remarks
	0.5 min	15 min	
1. Distillation of moisture onto ice nuclei	–	$2.5 \cdot 10^{-10}$	g/m^3 of dry ice (-5°C)
2. Heating the fog	149	–	cal/m^3
3. Distillation of moisture onto hygroscopic particles	1	10^{-3}	g/m^3 of saturated solution
4. Removal of drops	3.1	0.1	
5. Removal of drops together with air	4	–	
6. Coagulation of drops on reagent particles	12	1	g/m^3 of water

applicable at both negative and positive temperatures. The calculations were performed for fog 50 meters thick with a moisture content of 0.1 g/m^3 for times of 0.5 and 15 minutes required to remove the fog from the air [6].

The energy expenditures given in the table can be reduced by improving the technical equipment and the seeding methods. These data show that the effectiveness of methods of seeding supercooled fog is many orders of magnitude greater than that of other methods.

Data on the minimum dosages can be used to compare the various methods and estimate the influence of the zone-clearance time, but care must be exhibited, since the realizability of a number of methods is considerably poorer. With seeding using hygroscopic substances in the "slow-acting" version, a significant reduction in the specific consumption of reagent is accompanied by an abrupt increase in the total cleared area, a reduction in the reliability

of clearance, and a decrease in the achievable visibility limit.

Comprehensive analysis of methods of controlling warm fog relative to airport clearance shows that thermal methods are most suitable for this purpose. They do not involve the introduction of polluting particles into the atmosphere, they are fast-acting, and they depend only slightly on the microphysical characteristics of the fog. The actual fuel consumption does not differ greatly from the calculated minimum.

Analysis of Table 2 shows that only in the case of dissipating supercooled clouds can a comparatively small quantity of reagent give results that are of practical significance. This is why much attention has been devoted to development of this method.

Studies in the field of control of supercooled clouds and fog were directed toward solving basic problems arising during practical application of the method: 1) an increase in the reliability of the method and the possibility of predicting the results; 2) development of effective means for introducing the reagent.

For this purpose, a quantitative theory has been developed for the process of the formation of ice nuclei in a supercooled cloud when seeded with dry ice. This has been published in a number of works. By means of this theory we can determine the required dosage of reagent, and estimate the effectiveness of other reagents acting as cooling agents. The theory makes it possible to determine ways of seeking other reagents of the coolant class. It also makes it possible to determine the basic factors which influence the ice-forming effectiveness of the reagent.

At the same time study has been made of processes aiding the formation of breaks in a cloud. For this we must study processes of the propagation of crystals created artificially in a local volume, in the cloud layer. The use of theoretical methods of studying turbulent diffusion in the atmosphere has made it possible

to obtain an expression for the dependence of the width of the zone of crystallization propagation in a cloud on the time and the meteorological conditions.

All theoretical assumptions have been verified from a vast number of experiments carried out under natural conditions. The results of a group of theoretical and experimental works served as the basis for a scientifically-founded method of seeding operations and operations to determine the limits of applicability of the method.

Another important problem was the development of equipment for introducing a given amount of reagent into a cloud or fog. At present there are aircraft and surface devices for reagent dosing.

As a result of these studies, at present we have a reliable scientifically-based method for dissipating fog and clouds, and means for carrying it out have been developed. This method is being used experimentally at a number of airports in the USSR.

During these operations at USSR airports, artificial seeding has made possible more than 2000 additional airport operations.

The estimate of the feasibility of using these operations is greatly hindered by the lack of a method for evaluating the economic effectiveness. Approximate estimates have been made in the USSR and abroad for supercooled clouds and fog.

The economic effectiveness of operations to control fog and clouds

An approximate estimate of the economic effectiveness of the artificial seeding of clouds and fog was done in 1963 by the Planning-Economic Department of the Kazakh Territorial Administration of the Civil Air Fleet [CAF]. The money saved by the airport for air traffic during the airfield clearance period (from 10 January through 20 February) amounted to 50,000 rubles. This figure represents the losses that can be avoided by artificial seeding at one airport.

In the USSR there are at least 30 airports where such savings can be effected. Thus, the broad-scale introduction of seeding could prevent annual losses amounting to about 1.5 million rubles.

French specialists consider that when there are 30-50 hours of supercooled fog a year, operations on fog dispersion are profitable even when the airport is equipped with a system of fixed automatic-control devices. The cost of the equipment is completely justified by the profits obtained through the use of seeding in one year.

Much attention has been paid in the United States to evaluating the economic effectiveness. Table 3 gives an example of the relationship of seeding operation expenditures and the total dollar savings. These data are for the 1963-64 season. From the table we see that the ratio of expenses to savings is 1:5.

Table 3. Results of experiments on fog seeding in the United States (winter 1963-64)

Quantitative factors	Salt Lake City	Medford
Number of experiments:	8	8
successful	8	7
doubtful	0	1
unsuccessful	0	0
Weight of CO_2 used, lb.	625	2775
Number of operations as a result of seeding:	24	15
landings	14	6
takeoffs	10	9
Cost of seeding operations (dollars)	3300	525
Sum of avoided losses (dollars)	16,000	3000

In the United States, estimates have also been made of losses in four winter months suffered by United Air Lines due to poor weather, before seeding operations were undertaken. Losses, plus additional expenditures, amounted to about \$9 million. In the estimate, delays of more than 30 minutes from scheduled times were taken into consideration.

Of these $9 million, $3.4 million were due to headwinds and the lack of takeoff and landing minimums; $4 million were due to poor weather enroute to the destination airport. United Air Lines carries out 20% of its operations at these airports. For US internal carriers the loss is more than $35 million (due to poor weather and headwinds). From the example of the two airports we see that headwinds account for a negligibly small number of cases of the total number of diversions or delays. Specialists have concluded that even during the years most unfavorable for seeding, an appreciable economic effect is gained.

We can state that simple methods, not requiring expensive equipment, for the artificial dissipation of supercooled clouds and fog are undoubtedly profitable.

Methods for dissipating warm fog are practically never used, and therefore at present we can give only a theoretical evaluation of their economic effect. Operations were conducted at Orly Airport to estimate the cost of seeding warm fog and to compare this with the total possible prevented losses. The estimate was made for a period of 10 years (1968-1978); the results are given in Table 4.

Table 4. Economic effect of dispersion of warm fog

Method	Total avoided losses (mil. Fr. francs)	Capital outlay (mil. Fr. francs)	Operating costs (mil. Fr. francs)	Economic effect
Turbojet engines	43.5	33.49	12.98	- 2.97
Hot-gas generators with a fan	43.5	50.45	8.68	-15.63
Pulse-jet engines	43.5	42.5	7.55	- 6.55

As we see from the table, there are no direct advantages to be gained from dissipating warm fog; however, in the authors' opinion [5], the indirect benefits gained by increasing flight regularity and safety can equalize the negative balance obtained. We should also note that the calculations were done for specific climatic conditions. The great economic effectiveness stipulates the broader

use of fog dispersal methods abroad. The artificial dissipation of supercooled fog has been carried out since 1958 in France at Orly Airport. Particular attention has been devoted to surface methods of fog dissipation. Liquids with low boiling points were used as the reagents. At first, moving devices were used for the operation. To clear the airfield, 10 devices were used simultaneously. The method of dispersal improved from year to year. At the present time the system for introducing the reagent into the fog consists of a belt of stationary sprayers to which propane is fed from a common container. The devices are grouped according to prevailing wind directions. The devices are controlled automatically. In four seasons, 196 planes took off and 177 landed as a result of seeding operations.

After 24 December 1964 the fog-seeding operations at Orly Airport became productive. The fog-dispersal service became one of the airport service operations. Creation of the productive dissipation service is to be completed in 1967. The improved dissipation system consists of 60 propane sprayers around the perimeter of the airfield. Each sprayer has its own 600 kilogram propane container. The devices are automatically controlled. The control board for the units is located in the control tower. Turn-on of the units is controlled by an instrument that measures fog characteristics.

In the opinion of French specialists, the dispersal of supercooled fog from the ground using such a system is more preferable than using aircraft.

From the above we can conclude that there is at present, in practice, a favorable, reliable, economically suitable method for dispersing supercooled clouds.

Relative to methods for controlling warm clouds and fog we can state that any method requires great economic expense; however, the difference between avoided losses and expenses over a 10-year leriod is slight, and the methods can be used to increase air operational safety and regularity.

The above indicates that development of artifical dissipation methods is a pressing problem. In this connection we can formulate the basic problems for further study:

a) expand the limits of applicability of the method;

b) expand the use of ice-forming aerosols;

c) improve the prediction of landing conditions after dissipation methods have been used;

d) improve the dispersal equipment and methods;

e) expand the practical use of the methods at airports;

f) resort to field experiments in seeding warm fog in order to develop a method for airport clearing.

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